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Economically, do environmentally regulated firms perform worse?

Evidence from the German Manufacturing Sector

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The European Union Emissions Trading Scheme (EU ETS)

The cornerstone of EU's Climate Policy

- Cap-and-trade
- Inception in **2005** (3 Phases)
- **45% of GHG emissions**
- Installations performing **energy intensive activities** with total thermal combustion **capacity in excess of 20MW**.

How do regulated firms respond to the EU ETS?

Compliance options

1. **Surrender allowances** to legitimate its emissions or **sell the surplus** on the market
2. **Abate** through the change in input choice (e.g. fuel switch) or **adjust** its production process (e.g. investment in energy efficiency, reduction of fuel usage)
3. **Develop less emission-intensive products**
4. **Reduce** its output

Heterogeneous and **temporally different**!

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Research Question

What is the interplay between the **EU ETS** *and the* **cost efficiency** *of firms in the* **German manufacturing sector***?*

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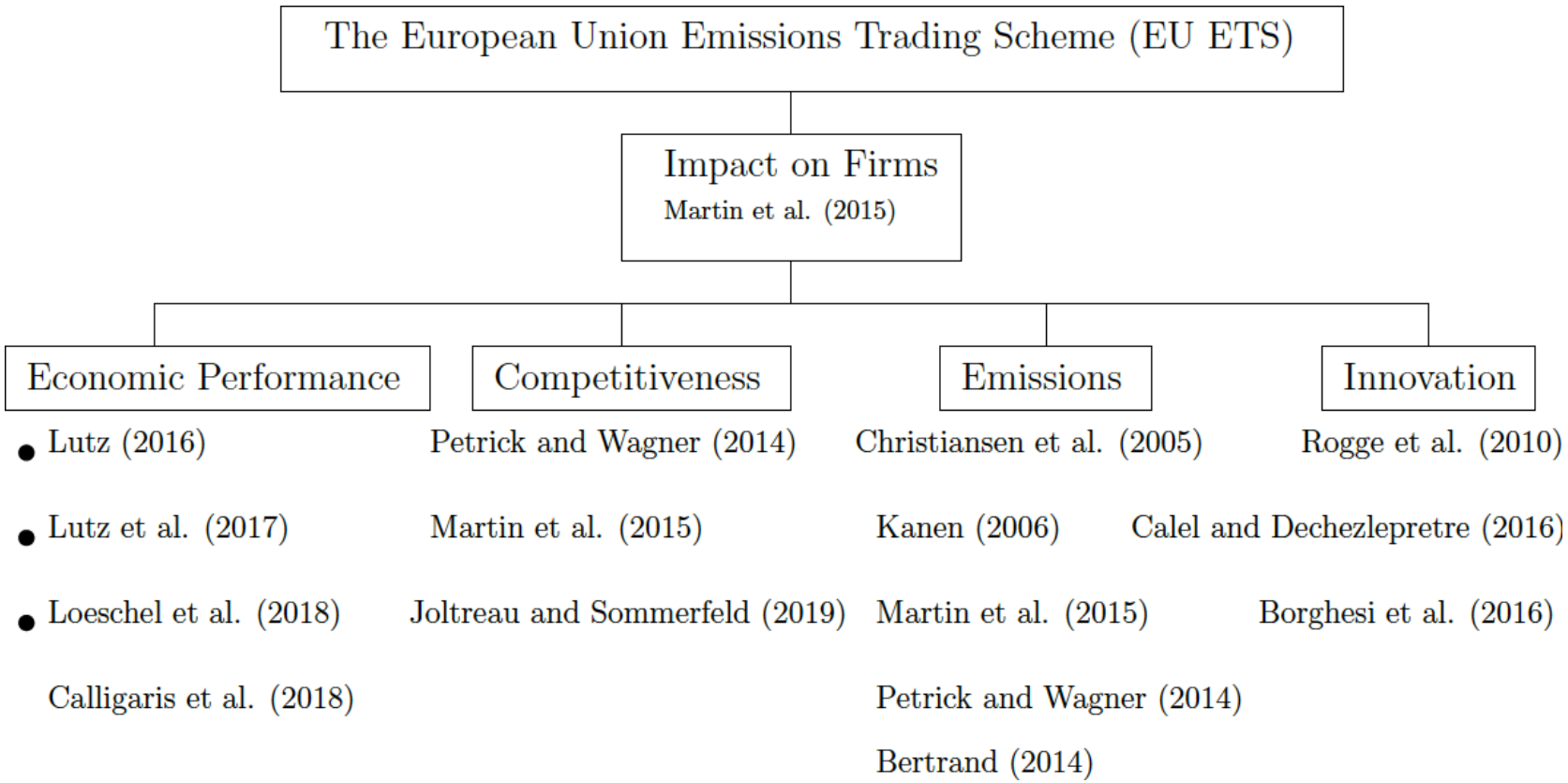
Preview of results

1. Potential to increase cost efficiency in most industries.
2. Exporting↑ CE↑.
3. EU ETS, active permits trading, R&D investment,↑ CE↓.
4. Industry ranking variation over time.
5. Evidence of induced innovation in a subset of industries.
6. CE (regulated firms) $<$ CE (non-regulated firms).
7. AIE $<$ TIE.
8. Evidence of a systemic overuse of capital.

Finding a niche



Occupying the niche

What I do?

- **Cost Function** Approach
- Cost (In)efficiency **Decomposition**
- Address **endogeneity** concerns

Why it matters?

- CE = AE x TE→ impact on costs
- Policy implications
- Endogeneity introduces bias in estimates

Occupying the niche

What I do?

- Account for the EU ETS **directly** in the frontier
- **Drivers** of Cost (In)efficiency

Why it matters?

- Relate policy to the **level** and **curvature** of the frontier.
- Relate policy to the **distance** from the frontier.

Occupying the niche

What I do?

- **Intra-** and **inter-industry** comparison of firms cost efficiency

Why it matters?

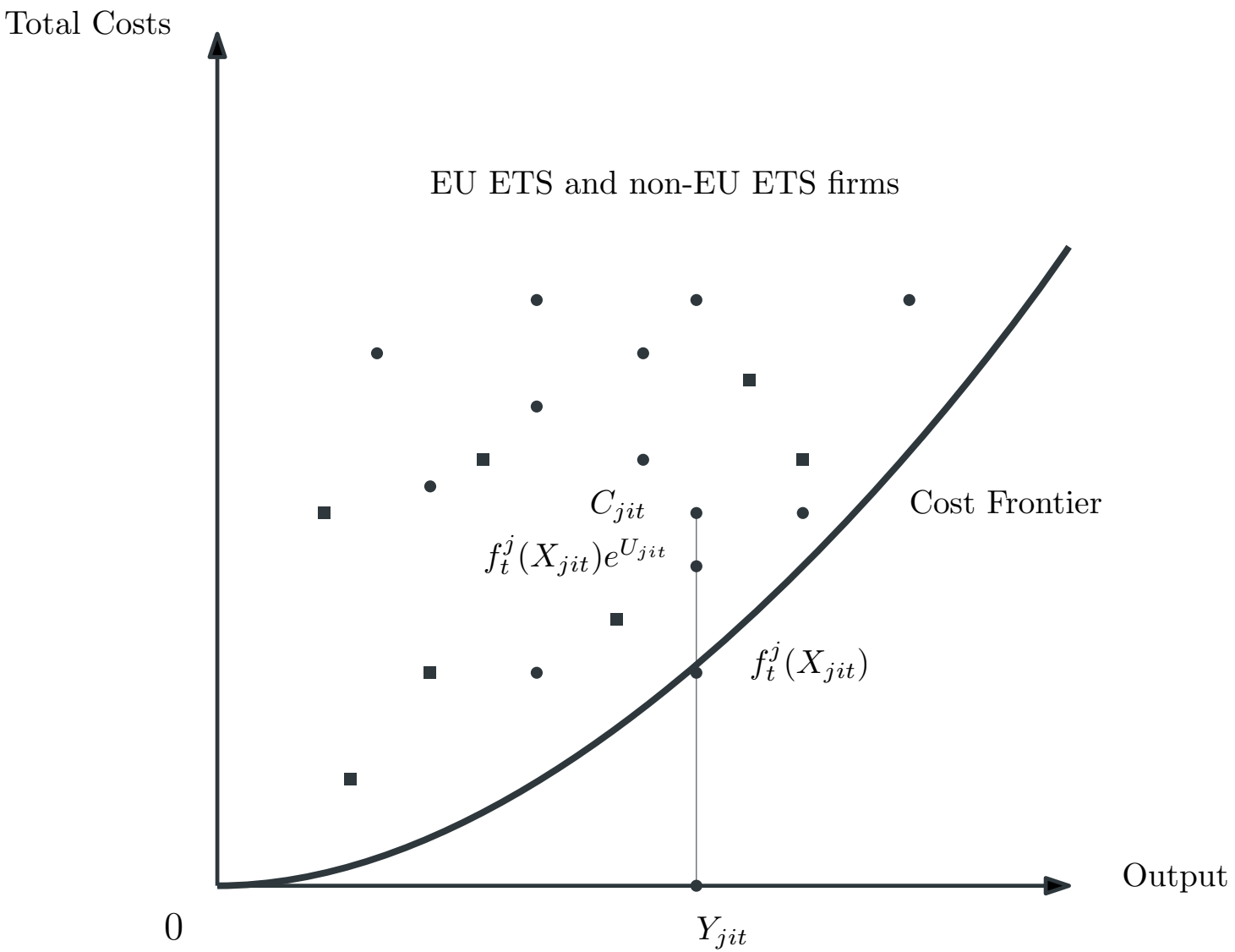
- Evidence of induced innovation in the long run
- Rank the performers

Hypotheses

Hypothesis 1

- The EU ETS has **no significant impact** on firm cost efficiency.

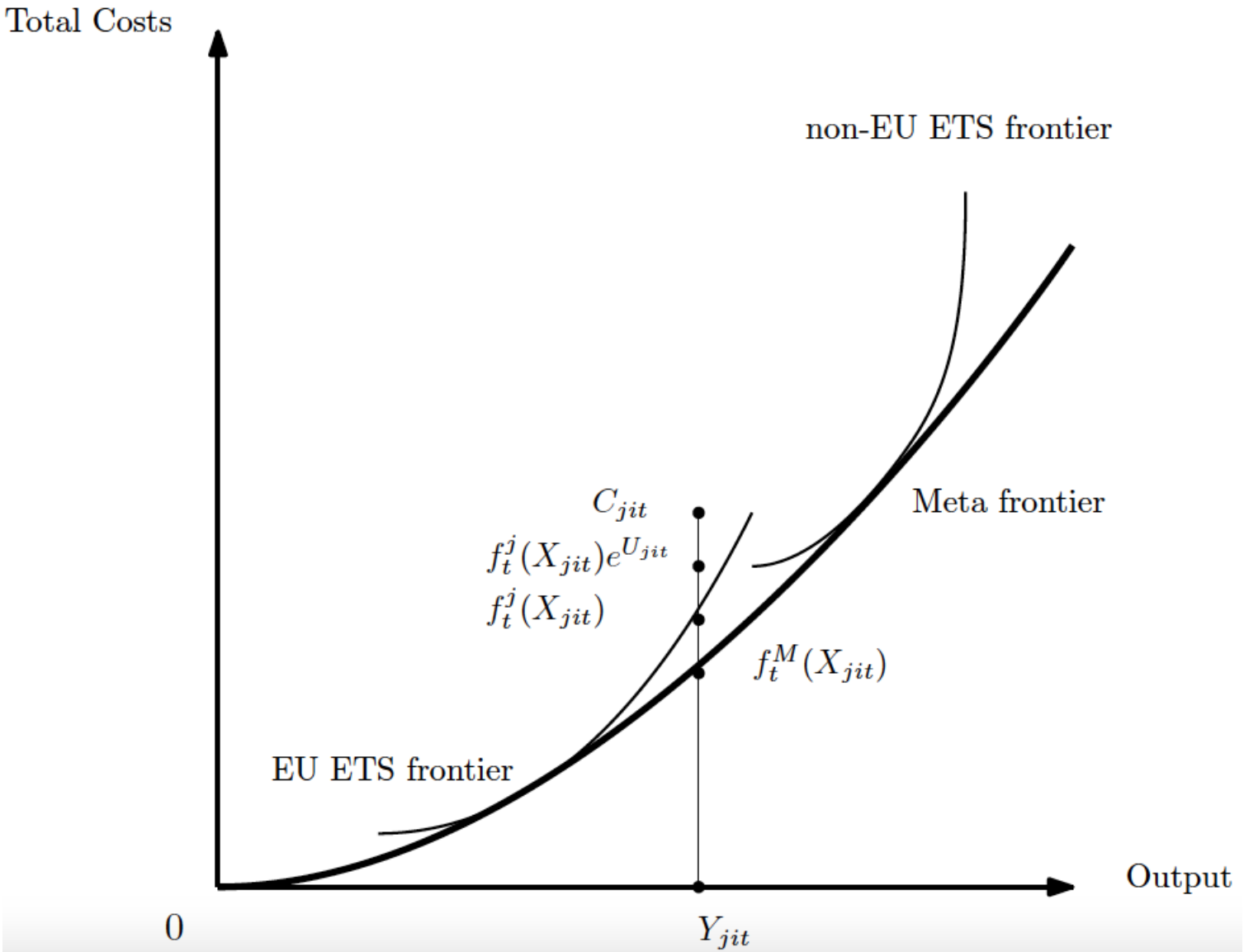
H1



Hypothesis 2

- The EU ETS results in the regulated and non-regulated firms operating under **heterogeneous frontiers** within an industry.

H2



Stochastic Cost Frontier Model
Battese and Coelli (1995)

Time-varying cost inefficiency effects model

$$lnTC_{it} = \alpha + \beta_1 lnY_{it} + \beta_2 lnP_{L_{it}} + \beta_3 lnP_{K_{it}} + \beta_4 lnP_{E_{it}} + \tau T + v_{it} + u_{it}$$

$$u_{it} = \boldsymbol{z_{it}}\delta + w_{it}, u_{it} \sim N^{+}(z_{it}\delta, \sigma_u^2)$$

- TC_{it}:Total costs
- Y_{it}: Gross value of production
- $P_{L_{it}}, P_{K_{it}}, P_{E_{it}}$: Input factor prices
- T: Time trend
- $v_{it} + u_{it}$: Composed error term
- z_{it}: ETS, $ACTRADE$, EXP, $RANDD$, $PHASE1$, $PHASE2$;

Stochastic Meta Cost Frontier Model
Huang et al. (2014)

First-step: Stochastic Cost Group Frontier Estimation

- **Cost frontier estimation for each group**
  intra- industry: regulated vs. non-regulated (2 groups)
  inter-industry: industry vs. the others (14 groups)
- **Group-specific cost efficiency**
- **Residuals prediction**

Second-step: Meta Frontier Estimation

$$ln\hat{TC}_{it} = \alpha + \beta_1 lnY_{it} + \beta_2 lnP_{L_{it}} + \beta_3 lnP_{K_{it}} + \beta_4 lnP_{E_{it}} + \tau T + v_{it}^M + u_{it}^M$$

$$u_{it}^M = a_0 + a_1 NORTH_{it} + a_2 EAST_{it} + a_3 WEST_{it} + \epsilon_{it}^M$$

Administrative firm-level data collected by the German statistical offices (AFiD)

- Remote-access
- Confidentiality and re-identification risk

Description

- All manufacturing firms with more than 20 employees
- General characteristics → revenues, value added, employment, investment
- Fuel and electricity use
- Period: 2003-2014
- 64377 firms
- To identify regulated firms: merge AFiD to EUTL

Number of regulated firms

		2005			2010			2014		
ISIC Rev.4	Industry	Total	Unregulated	Regulated	Total	Unregulated	Regulated	Total	Unregulated	Regulated
10	Food products	4877	4836	41	4878	4832	46	4988	4940	48
11	Beverages	619	610	9	519	507	12	492	478	14
12	Tobacco products	25	-	-	21	-	-	22	-	-
13	Textiles	845	838	7	697	691	6	678	672	6
14	Wearing apparel	514	514	-	313	313	-	270	270	-
15	Leather and related products	188	188	-	137	137	-	122	122	-
16	Wood and products of wood and cork	1395	1380	15	1161	1139	22	1151	1127	24
17	Paper and paper products	858	772	86	825	723	102	794	687	107
18	Printing and reproduction of recorded media	1682	-	-	1490	1487	3	1316	1311	5
19	Coke and refined petroleum products	51	36	15	45	29	16	50	33	17
20	Chemicals and chemical products	1204	1134	70	1218	1138	80	1286	1201	85
21	Pharmaceutical products	285	278	7	255	249	6	275	268	7
22	Rubber and plastic products	2799	2788	11	2749	2734	15	2871	2857	14
23	Other nonmetallic mineral products	1909	1743	166	1646	1469	177	1668	1490	178
24	Basic metals	941	882	59	924	857	67	938	865	73
25	Fabricated metal products	6358	6354	4	6750	6744	6	7287	7284	3
26	Computer, electronic and optical products	1772	1767	5	1632	1628	4	1764	1761	3
27	Electrical equipment	2063	2056	7	1906	1899	7	2011	2004	7
28	Machinery and equipment n.e.c.	6177	6167	10	5298	5283	15	5530	5516	14
29	Motor vehicles, trailers, and semitrailers	1190	1180	10	1093	1085	8	1063	1054	9
30	Other transport equipment	350	341	9	256	249	7	281	273	8
31	Furniture	1095	1095	-	981	981	-	1000	1000	-
32	Other manufacturing	1624	1620	4	1458	-	-	1521	-	-
33	Repair and installation of mach. and equip.	308	308	-	1494	1488	6	1647	1641	6
	Total	39129	36887	535	37746	35662	605	39025	36854	628

Descriptive statistics

ISIC Rev. 4	Total Costs (EUR 1000)	Output (EUR 1000)	Price of Capital (EUR 1000)	Price of Labour (EUR 1000)	Price of Energy (EUR/kWh)	Capital Stock (EUR 1000)	Number of Employees	Energy use (Mwh)	Emissions (tCO_2)	Number of Firms
10	20161 (63471)	20839 (79875)	1,43 (4,03)	20,09 (9,84)	0,14 (1,02)	6391 (23000)	99 (224)	11700 (81000)	4050 (22314)	8367
13	10262 (19241)	12405 (23556)	1,29 (2,83)	26,32 (9,62)	0,11 (1,04)	5249 (10700)	99 (131)	9611 (25900)	3808 (9388)	1289
16	12715 (24323)	1194 (29417)	1,44 (4,19)	26,39 (8,46)	0,19 (1,65)	5362 (17000)	67 (115)	16800 (102000)	2821 (15882)	2149
19	1036800 (2982053)	677902 (2198909)	2,53 (4,58)	49,96 (16,51)	0,45 (3,37)	150000 (309000)	388 (725)	1640000 (4300000)	468189 (1230527)	74
20	67312 (361984)	78205 (373298)	1,96 (23,28)	39,82 (12,96)	0,35 (14,25)	36500 (184000)	263 (1234)	218000 (2280000)	67042 (609983)	1968
21	109414 (384318)	104273 (357973)	1,62 (3,29)	40,69 (13,61)	0,18 (1,60)	57300 (258000)	452 (1295)	26400 (92000)	9325 (27786)	450
22	22926 (65626)	19327 (55109)	1,14 (6,28)	29,36 (9,29)	0,14 (1,69)	7809 (23200)	129 (319)	8548 (34500)	4456 (14938)	4218

Descriptive statistics cont.

ISIC Rev. 4	Total Costs (EUR 1000)	Output (EUR 1000)	Price of Capital (EUR 1000)	Price of Labour (EUR 1000)	Price of Energy (EUR/kWh)	Capital Stock (EUR 1000)	Number of Employees	Energy use (Mwh)	Emissions (tCO_2)	Number of Firms
24	50556 (191335)	86211 (365361)	1,11 (3,40)	36,15 (10,13)	0,16 (2,15)	24500 (112000)	268 (838)	265000 (2790000)	97588 (907727)	1388
25	15104 (31800)	12985 (31952)	1,49 (16,93)	30,40 (9,59)	0,14 (1,29)	4737 (12600)	91 (166)	4180 (25700)	1942 (12127)	10583
26	36711 (149353)	31159 (135456)	1,68 (3,52)	37,48 (13,69)	0,47 (19,40)	12200 (90800)	166 497	4650 (35400)	2558 (18439)	3029
27	45680 (534098)	35504 (339797)	1,60 (3,28)	33,20 (11,55)	0,17 (1,35)	10700 (120000)	234 2604	5560 (49400)	2759 (23655)	3248
28	31269 (151348)	29633 (120373)	1,71 (12,79)	37,39 (12,20)	0,20 (6,20)	7912 (54100)	165 (792)	4322 (34600)	1934 (14188)	9521
29	164582 (1256032)	221849 (2304456)	1,79 (7,89)	33,10 (12,02)	0,50 (11,96)	60600 (584000)	729 (5904)	31900 (282000)	15432 (133666)	1807
30	71503 (305896)	88776 (388130)	1,56 (3,31)	35,37 (12,77)	0,19 (3,29)	24100 (142000)	440 (1623)	17800 (189000)	7410 (84517)	2171

Parameter estimates of industry-specific stochastic cost frontiers

ISIC Rev.4	ln$Y$	lnP_E	lnP_L	T
10	0.647^{***}	0.162^{***}	0.708^{***}	-0.013^{***}
13	0.708^{***}	0.099^{***}	0.858^{***}	-0.013^{***}
16	0.726^{***}	0.047^{***}	0.885^{***}	-0.005^{**}
19	0.809^{***}	0.026	0.533^{***}	0.009
20	0.742^{***}	0.062^{***}	0.876^{***}	-0.021^{***}
21	0.845^{***}	0.142^{***}	0.833^{***}	-0.006^{**}
22	0.814^{***}	0.158^{***}	0.770^{***}	-0.020^{***}
24	0.708^{***}	0.052^{***}	0.971^{***}	-0.013^{***}
25	0.761^{***}	0.111^{***}	0.863^{***}	0.003^{***}
26	0.779^{***}	0.038^{***}	0.929^{***}	-0.013^{***}
27	0.807^{***}	0.087^{***}	0.854^{***}	-0.031^{***}
28	0.801^{***}	0.085^{***}	0.913^{***}	0.001
29	0.772^{***}	0.060^{***}	0.940^{***}	-0.011^{***}
30	0.671^{***}	0.013	1.000^{***}	−0.004

Notes: *p<0.10, **p<0.05,***p<0.01; Source: RDC of the Federal Statistical Office and Statistical Offices of the Länder, [survey years 2003-2014], own calculations.

Cost inefficiency drivers and variance parameters

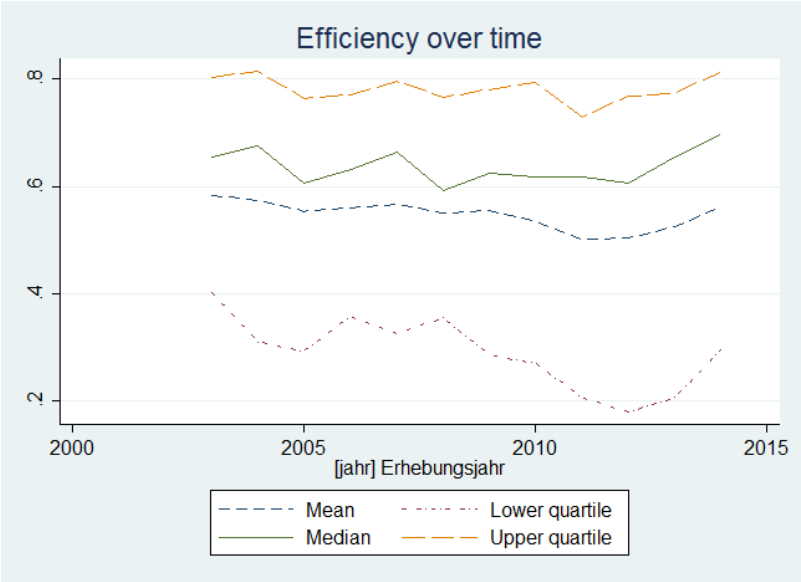
ISIC Rev.4	ETS	$RANDD$	EXP	$ACTTRADE$	$PHASE1$	$PHASE2$	σ_u	$\lambda_u = \sigma_u/\sigma_v$
10	0.838^{***}	0.482^{***}	-0.392^{***}	0.192^{*}	-0.121	-0.080	0.455^{***}	0.882^{***}
13	0.764	0.238^{***}	-0.738^{***}	0.349	0.445	0.275	-0.592^{***}	1.622^{***}
16	0.496^{***}	0.327^{***}	-0.005	-0.217	0.125	0.156	0.573^{***}	1.809^{***}
19	1.444^{***}	-1.039^{***}	-2.144^{***}	0.847^{**}	0.455	0.116	1.353^{***}	5.050^{***}
20	0.935^{***}	0.308^{***}	-0.887^{***}	0.676^{***}	0.001	0.158	0.795^{***}	1.955^{***}
21	1.723^{***}	0.450^{***}	-1.408^{***}	0.361	-0.790	-0.701	0.946^{***}	2.700^{***}
22	0.337^{**}	0.338^{***}	-0.189^{***}	0.196	-0.051	0.124	0.405^{***}	1.254^{***}
24	0.301^{***}	0.428^{***}	-0.074	0.316^{***}	0.078	0.127	0.230^{***}	0.480^{***}
25	0.917^{***}	0.512^{***}	-0.330^{***}	0.240	-0.303	-0.219	0.502^{***}	1.542^{***}
26	2.319^{**}	0.204^{***}	-0.692^{***}	-0.082	-0.245	0.160	0.776^{***}	2.148^{***}
27	0.857^{**}	0.246^{***}	-0.447^{***}	0.622^{*}	-0.283	0.164	0.631^{***}	1.853^{***}
28	1.138^{***}	0.216^{***}	-1.165^{***}	0.060	-0.006	0.008	0.706^{***}	2.244^{***}
29	1.246^{***}	0.647^{***}	-1.265^{***}	0.194	0.196	0.104	0.699^{***}	1.764^{***}
30	1.527^{***}	0.790^{***}	-1.112^{***}	-0.066	0.218	0.104	1.044^{***}	3.322^{***}

Average cost efficiency scores across industries

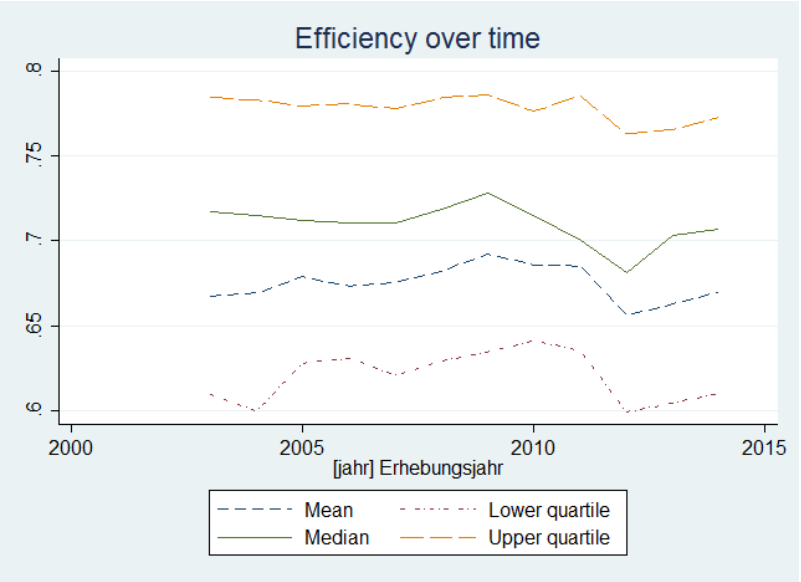
ISIC Rev.4	Industry	CE	sd	p10	p50	p75	N
10	Food	0.734	0.095	0.615	0.748	0.802	20720
13	Textiles	0.752	0.110	0.610	0.776	0.830	4630
16	Wood and products of wood and cork	0.652	0.154	0.425	0.682	0.773	4622
19	Coke and refined petroleum products	0.547	0.273	0.128	0.638	0.784	488
20	Chemicals and chemical products	0.663	0.157	0.430	0.704	0.780	9396
21	Pharmaceutical products	0.675	0.157	0.452	0.711	0.777	2129
22	Rubber and plastic products	0.750	0.104	0.612	0.771	0.826	10247
24	Basic metals	0.792	0.111	0.641	0.843	0.868	7154
25	Fabricated metal products	0.724	0.121	0.570	0.747	0.810	21673
26	Computer, electronic and optical products	0.669	0.152	0.468	0.701	0.779	8351
27	Electrical equipment	0.691	0.136	0.516	0.716	0.789	10653
28	Machinery and equipment n.e.c.	0.748	0.122	0.591	0.776	0.832	26574
29	Motor vehicles, trailers, and semitrailers	0.730	0.126	0.575	0.760	0.817	7432
30	Other transport equipment	0.593	0.194	0.316	0.632	0.742	2622

Source: RDC of the Federal Statistical Office and Statistical Offices of the Länder, [survey years 2003-2014], own calculations.

Mean cost-efficiency scores

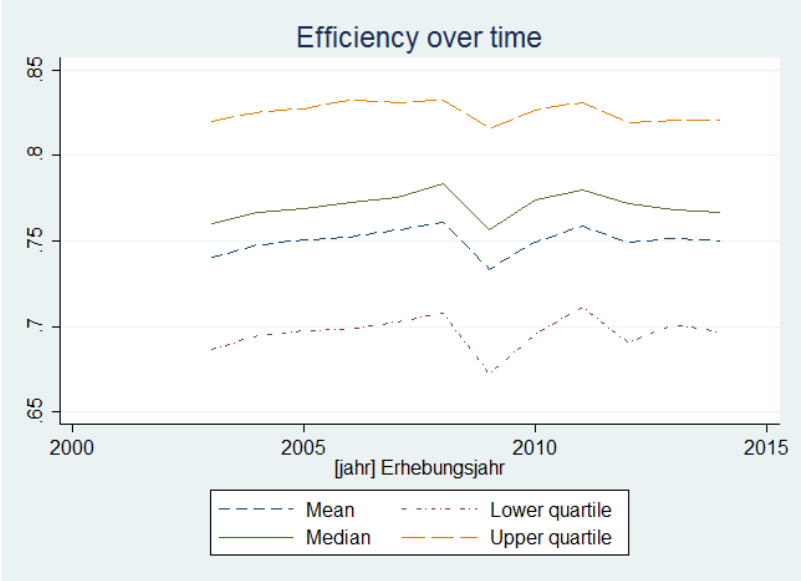


(a) Coke and refined petroleum products

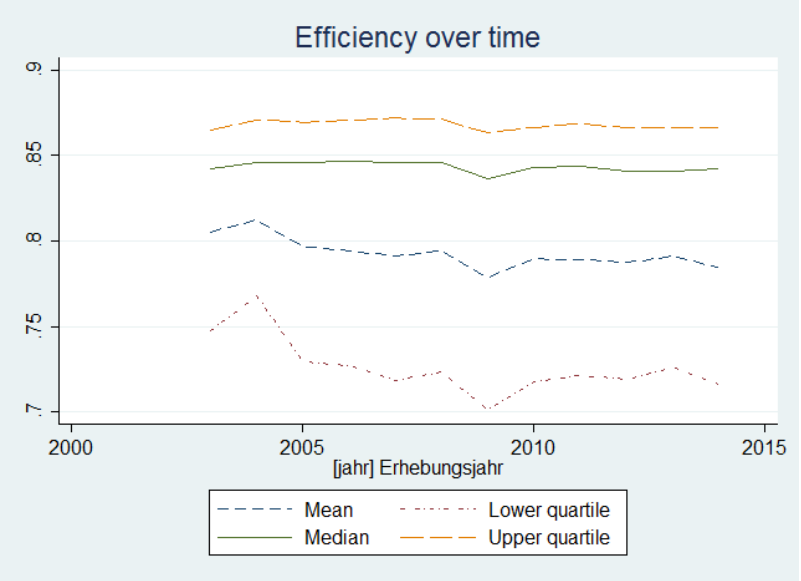


(b) Pharmaceutical products

Mean cost-efficiency scores (cont.)

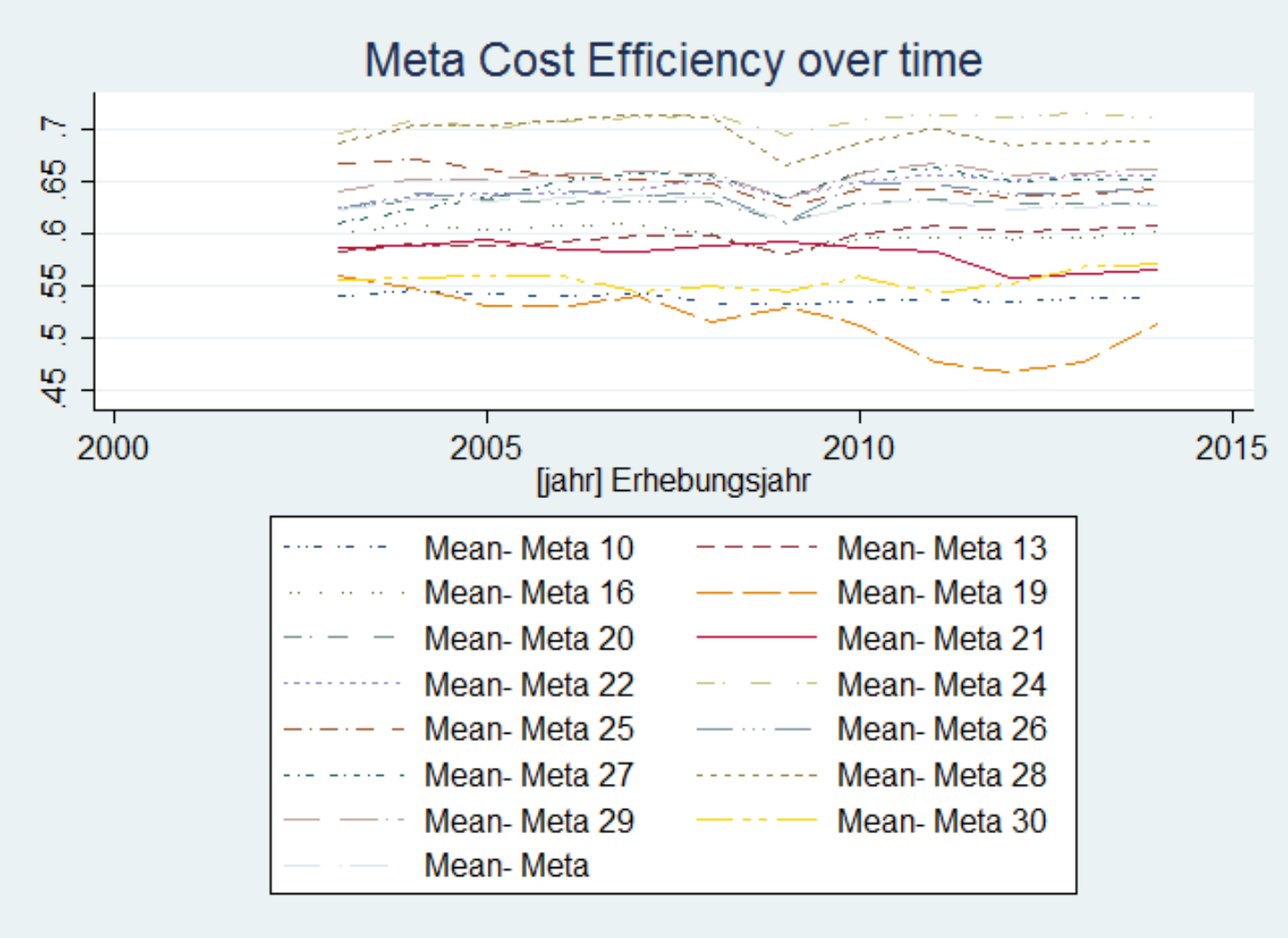


(c) Rubber and plastic products



(d) Basic metals

Graphical inter-industry comparison



Inter-industry comparison

Year	2003				2005				2010			
ISIC Rev.4	CE_{pooled}	CE_{group}	CGR	MCE	CE_{pooled}	CE_{group}	CGR	MCE	CE_{pooled}	CE_{group}	CGR	MCE
10	0,6291	0,7367	0,7328	0,5405	0,6323	0,7349	0,7387	0,5423	0,6223	0,7322	0,7305	0,5352
	(0,1701)	(0,0929)	(0,1593)	(0,1369)	(0,1648)	(0,0959)	(0,1574)	(0,1339)	(0,1683)	(0,0934)	(0,1606)	(0,1389)
13	0,6746	0,7509	0,7758	0,5828	0,6810	0,7527	0,7811	0,5884	0,6853	0,7535	0,7966	0,6008
	(0,1205)	(0,1033)	(0,0647)	(0,0926)	(0,1292)	(0,1136)	(0,0647)	(0,1005)	(0,1231)	(0,1065)	(0,0632)	(0,0974)
16	0,7041	0,6503	0,9228	0,5998	0,7068	0,6549	0,9222	0,6033	0,7010	0,6493	0,9190	0,5962
	(0,1273)	(0,1544)	(0,0250)	(0,1419)	(0,1233)	(0,1509)	(0,0254)	(0,1377)	(0,1271)	(0,1506)	(0,0281)	(0,1376)
19	0,6895	0,5834	0,9125	0,5598	0,6633	0,5540	0,9211	0,5309	0,6378	0,5349	0,9297	0,5126
	(0,2743)	(0,2751)	(0,1683)	(0,2835)	(0,2597)	(0,2588)	(0,1515)	(0,2665)	(0,2616)	(0,2767)	(0,1358)	(0,2774)
20	0,7004	0,6667	0,9363	0,6241	0,7103	0,6731	0,9423	0,6340	0,7139	0,6619	0,9522	0,6301
	(0,1486)	(0,1523)	(0,0145)	(0,1424)	(0,1455)	(0,1492)	(0,0141)	(0,1400)	(0,1500)	(0,1573)	(0,0117)	(0,1495)
21	0,6658	0,6675	0,8790	0,5870	0,6721	0,6790	0,8748	0,5941	0,6703	0,6859	0,8554	0,5879
	(0,1597)	(0,1703)	(0,0528)	(0,1568)	(0,1541)	(0,1571)	(0,0543)	(0,1447)	(0,1404)	(0,1403)	(0,0563)	(0,1307)
22	0,6904	0,7403	0,8454	0,6256	0,7037	0,7506	0,8519	0,6393	0,7126	0,7495	0,8678	0,6501
	(0,1180)	(0,1086)	(0,0412)	(0,0952)	(0,1136)	(0,1038)	(0,0382)	(0,0921)	(0,1124	(0,1069)	(0,0343)	(0,0940)
24	0,7101	0,8053	0,8682	0,6970	0,7297	0,7969	0,8846	0,7021	0,7352	0,7896	0,9015	0,7096
	(0,1256)	(0,0864)	(0,0505)	(0,0680)	(0,1219)	(0,1071)	(0,0451)	(0,0836)	(0,1234)	(0,1142)	(0,0378)	(0,0948)

Inter-industry comparison (cont.)

Year	2003				2005				2010			
ISIC Rev.4	CE_{pooled}	CE_{group}	CGR	MCE	CE_{pooled}	CE_{group}	CGR	MCE	CE_{pooled}	CE_{group}	CGR	MCE
25	0,7353	0,7257	0,9204	0,6675	0,7299	0,7257	0,9133	0,6625	0,7131	0,7232	0,8889	0,6427
	(0,1080)	(0,1227)	(0,0178)	(0,1116)	(0,1123)	(0,1240)	(0,0194)	(0,1127)	(0,1079)	(0,1153)	(0,0243)	(0,1029)
26	0,7164	0,6574	0,9485	0,6236	0,7283	0,6700	0,9497	0,6362	0,7413	0,6797	0,9540	0,6485
	(0,1322)	(0,1511)	(0,0110)	(0,1437)	(0,1296)	(0,1490)	(0,0124)	(0,1418)	(0,1282)	(0,1481)	(0,0084)	(0,1415)
27	0,6829	0,6734	0,9061	0,6106	0,7076	0,6915	0,9175	0,6348	0,7392	0,6998	0,9422	0,6593
	(0,1312)	(0,1384)	(0,0234)	(0,1286)	(0,1195)	(0,1293)	(0,0200)	(0,1208)	(0,1110)	(0,1273)	(0,0115)	(0,1200)
28	0,7422	0,7305	0,9409	0,6874	0,7547	0,7520	0,9371	0,7048	0,7367	0,7413	0,9285	0,6883
	(0,1066)	(0,1282)	(0,0114)	(0,1218)	(0,0998)	(0,1183)	(0,0121)	(0,1121)	(0,1047)	(0,1221)	(0,0149)	(0,1144)
29	0,6938	0,7225	0,8871	0,6414	0,7067	0,7334	0,8897	0,6527	0,7111	0,7324	0,8990	0,6587
	(0,1317)	(0,1250)	(0,0271)	(0,1143)	(0,1307)	(0,1245)	(0,0260)	(0,1135)	(0,1343)	(0,1290)	(0,0233)	(0,1180)
30	0,6863	0,5967	0,9327	0,5558	0,6837	0,6011	0,9310	0,5606	0,6986	0,5924	0,9451	0,5590
	(0,1654)	(0,1996)	(0,0384)	(0,1851)	(0,1721)	(0,2070)	(0,0543)	(0,1930)	(0,1400)	(0,1849)	(0,0304)	(0,1736)

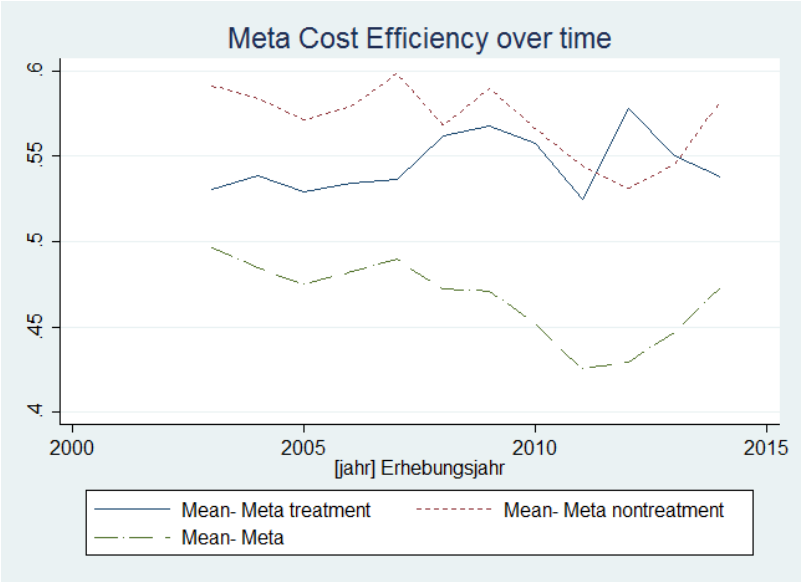
Inter-industry comparison (cont.)

	2003		2005		2010	
Ranking	SCF	MCF	SCF	MCF	SCF	MCF
1.	24	24	24	28	24	24
2.	13	28	13	24	13	28
3.	22	25	28	25	22	27
4.	10	29	22	29	28	29
5.	28	22	10	22	29	22
6.	25	20	29	26	10	26
7.	29	26	25	27	25	25
8.	27	27	27	20	27	20
9.	21	16	21	16	21	13
10.	20	21	20	21	26	16
11.	26	13	26	13	20	21
12.	16	19	16	30	16	30
13.	30	30	30	10	30	10
14.	19	10	19	19	19	19

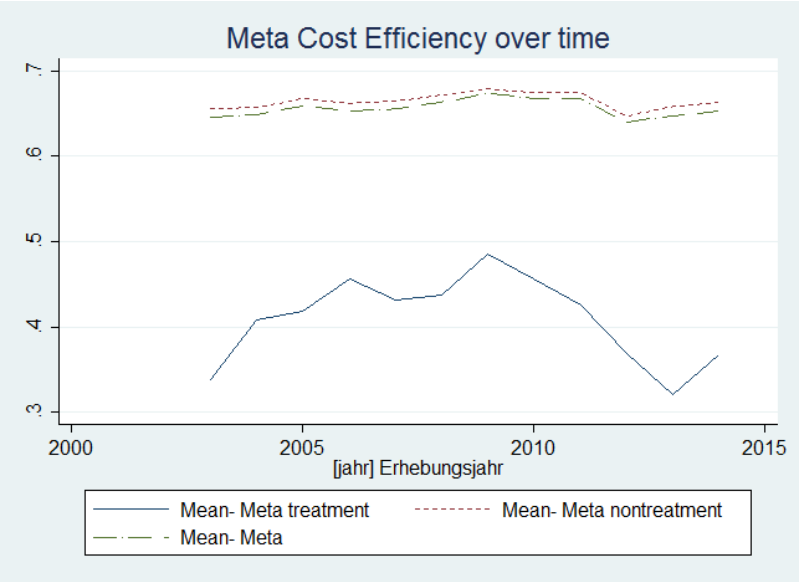
Intra-industry comparison

Year	CE	CGR	MCE	CE	CGR	MCE
ISIC Rev. 4 (19)		Regulated firms			Non-regulated firms	
2003	0,8262	0,6259	0,5309	0,7023	0,8415	0,5915
	(0,1816)	(0,1767)	(0,2168)	(0,2264)	(0,0515)	(0,1915)
2005	0,8015	0,6382	0,5292	0,6878	0,8268	0,5714
	(0,2162)	(0,1753)	(0,2365)	(0,2107)	(0,0670)	(0,1825)
2010	0,7732	0,6972	0,5573	0,6865	0,8011	0,5662
	(0,2416)	(0,1500)	(0,2444)	(0,2357)	(0,1069)	(0,2103)
ISIC Rev. 4 (21)		Regulated firms			Non-regulated firms	
2003	0,5709	0,5917	0,3378	0,6714	0,9773	0,6563
	(0,1265)	(0,1577)	(0,1124)	(0,1673)	(0,0024)	(0,1638)
2005	0,6228	0,6719	0,4190	0,6832	0,9776	0,6680
	(0,1544)	(0,1794)	(0,1536)	(0,1536)	(0,0024)	(0,1503)
2010	0,6431	0,6638	0,4259	0,6899	0,9786	0,6752
	(0,1429)	(0,2128)	(0,1553)	(0,1365)	(0,0018)	(0,1336)

Intra-industry comparison of yearly mean meta cost efficiency scores



(e) Coke and refined petroleum products



(f) Pharmaceutical products

Discussion

Explanations

- Regulation of less cost efficient firms
- The impact materializes beyond energy price increase
- Short run shock? (R&D)

Limitations

- Endogeneity
- Neglecting other regulatory instruments
- SUTVA

The road ahead

1. Trans-log cost function
2. Panel data model accounting for firm-fixed effects & unobserved heterogeneity
3. Measure the level of persistent and transient cost inefficiency
4. Comparative analysis of endogeneity adjusted/non-adjusted SF results
5. MFA confidence intervals + tests
6. The effect of the EU ETS on costs

Cost efficiency decomposition results

	No systematic error									With systematic error
$Year$	TE	TIE	AIE_E	AIE_K	$Count$ (%)	RTS	$C_{ratioTIE}$	$C_{ratioAIE}$	$C_{ratioBOTH}$	$Count$ (%)
ISIC Rev. 4 (16)										
2003	0,6808	0,4336	-0,0714	-0,0918	12,01	1,3032	0,4294	0,0690	0,5274	25,45
	(0,0837)	(0,1528)	(0,9635)	(0,6498)			(0,2180)	(0,1162)	(0,2807)	
2005	0,7256	0,3545	-0,0608	-0,0741	12,20	1,3091	0,3308	0,0757	0,4301	25,56
	(0,0661)	(0,1067)	(0,9955)	(0,6728)			(0,1200)	(0,1287)	(0,1989)	
2010	0,7868	0,3321	-0,1375	-0,1178	16,29	1,2953	0,0025	0,0862	0,0889	34,57
	(0,0221)	(0,1005)	(1,1043)	(0,6821)			(0,0001)	(0,1254)	(0,1257)	
ISIC Rev. 4 (20)										
2003	0,6193	0,5595	-0,0479	-0,0698	33,31	1,1827	0,6864	0,0744	0,8167	59,88
	(0,1168)	(0,2513)	(1,2425)	(0,5968)			(0,4877)	(0,1134)	(0,5937)	
2005	0,6885	0,4206	-0,0385	-0,0570	32,23	1,1647	0,4512	0,0780	0,5654	56,98
	(0,0806)	(0,1656)	(1,2568)	(0,5848)			(0,1976)	(0,1118)	(0,2800)	
2010	0,6691	0,4572	-0,0706	-0,0688	36,27	1,2035	0,4799	0,1157	0,6562	65,79
	(0,0855)	(0,1690)	(1,3943)	(0,6237)			(0,2294)	(0,3523)	(0,6112)	
ISIC Rev. 4 (25)										
2003	0,6940	0,4114	-0,0280	-0,0707	12,83	1,1950	0,4571	0,0471	0,5253	23,96
	(0,0958)	(0,1994)	(0,8331)	(0,5660)			(0,3922)	(0,0745)	(0,4226)	
2005	0,6879	0,4207	-0,0246	-0,0658	13,01	1,2230	0,4536	0,0481	0,5228	24,21
	(0,0882)	(0,1646)	(0,8274)	(0,5625)			(0,3462)	(0,0678)	(0,3748)	
2010	0,6893	0,04007	-0,0320	-0,0672	16,92	1,2184	0,0006	0,0475	0,0481	31,39
	(0,0923)	(0,1406)	(0,8039)	(0,5347)			(0,0004)	(0,0734)	(0,0730)	

Parametric DD approach with conditioning strategies

$$ln(CE)_{it} = \beta_0 + \tau_1 ETS_i \times Phase1_t + \tau_2 ETS_i \times Phase2_t + \tau_3 ETS_i \times Phase3_t + z_{it}\Psi + \alpha_i + \phi_t + \gamma_s + \eta_{st} + \epsilon_{it} \quad (1)$$

- ϕ_t: Year-fixed effects
- ϵ_t: Zero-mean error term
- $z_{it}\Psi$: Capital stock, emissions, energy use, output per employee.
- α_i: Firm-fixed effects
- γ_s: Industry-fixed effects
- η_{st}: Industry-fixed effects x Year-fixed effects

Non-parametric DD approach with nearest-neighbor matching

$$\hat{\tau} = \frac{1}{N} \sum_{j \in I_1} \left\{ (CE_{jt'}(1) - CE_{jt^0}(0)) - \sum_{k \in I_0} w_{jk} (CE_{kt'}(1) - CE_{kt^0}(0)) \right\} \quad (2)$$

Parametric DD approach- Full sample

Dependent Variable: Cost efficiency in logs	
Full sample	
Phase1	-0.153*
Phase2	-0.161*
Phase3	-0.157*
Year FE	yes
Firm FE	yes
Industry FE	yes
Industry × Year FE	yes
Additional Controls	yes
# Observations	175359

Nonparametric DD approach- Full sample

Dependent Variable:	Cost efficiency in logs		
Full sample	one neighbor	five neighbors	twenty neighbors
Phase1	-0.140***	-0.154***	-0.157***
Phase2	-0.143***	-0.166***	-0.171***
Phase3	-0.140***	-0.167***	-0.169***
Year FE	yes	yes	yes
Firm FE	yes	yes	yes
Industry FE	yes	yes	yes
Industry × Year FE	yes	yes	yes
Additional Controls	yes	yes	yes
# Observations	7042	11529	19444

Parametric DD approach- Industry level

Dependent Variable:	Cost efficiency in logs			
ISIC Rev.4	19	21	22	24
Phase1	-0.086	-0.092 **	-0.109***	-0.272***
Phase2	-0.034	-0.126***	-0.201***	-0.311***
Phase3	-0.117	-0.320***	-0.171***	-0.277***
Year FE	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes
Additional Controls	yes	yes	yes	yes
# Observations	487	2129	10242	7154

Nonparametric DD approach- Industry level

Dependent Variable:	Cost efficiency in logs											
ISIC Rev.4	19			21			22			24		
# Neighbors	1	5	20	1	5	20	1	5	20	1	5	20
Phase1	-0.073	-0.071	-0.089*	-0.064	-0.067	-0.075	-0.110***	-0.119***	-0.113***	-0.271***	-0.274***	-0.271***
Phase2	-0.091	-0.050	-0.045	-0.190**	-0.178***	-0.103	-0.205***	-0.218***	-0.204***	-0.316***	-0.322***	-0.310***
Phase3	-0.175**	-0.118	-0.105	-0.334***	-0.322***	-0.256***	-0.205***	-0.178***	-0.182***	-0.284***	-0.289***	-0.277***
Year FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Additional Controls	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
# Observations	220	269	359	102	229	419	151	340	732	914	1496	2492

Nonparametric DD approach- Industry level

Dependent Variable: Meta cost efficiency in logs		
ISIC Rev.4	19	21
Phase1	0.018	-0.001
Phase2	0.051	-0.018
Phase3	0.002	-0.129*
Year FE	yes	yes
Firm FE	yes	yes
Additional Controls	yes	yes
# Observations	487	2129

What is a cap-and-trade?

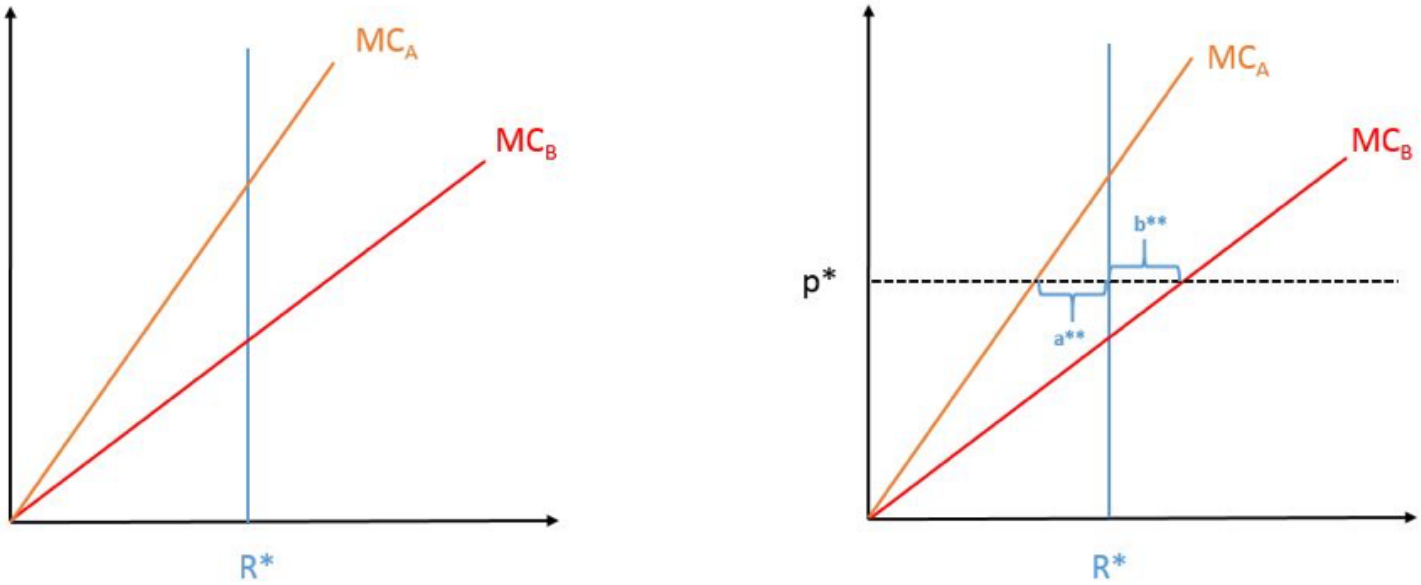


Figure 1: Abatement Costs Levelization; Source: Own Depiction

What is a cap-and-trade? (cont.)

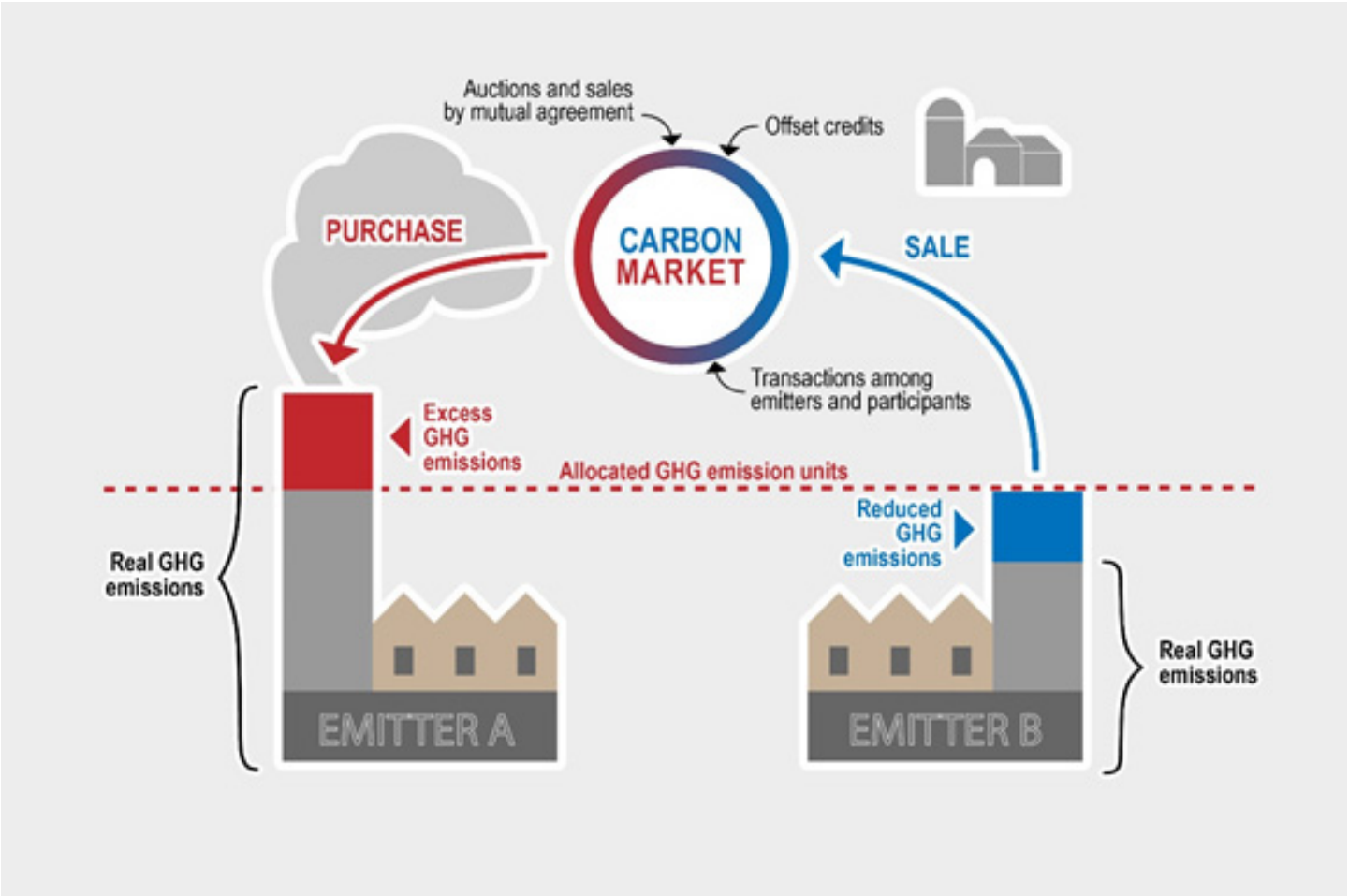


Figure 2: Basics of cap-and-trade;
Source:http://nsfa-fane.ca/2017/03/17/cap-and-trade-and-agriculture/

EUA Price Development

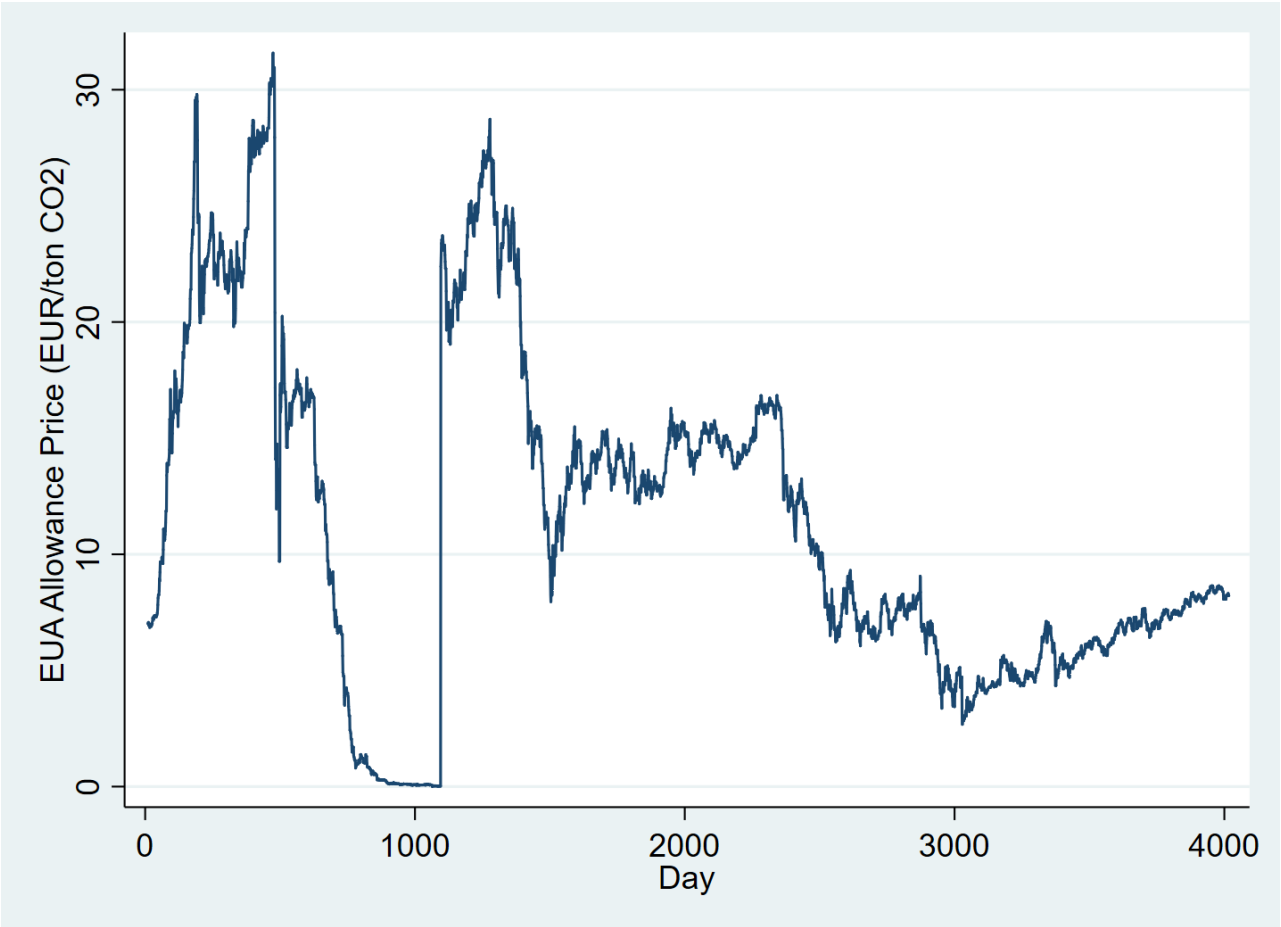


Figure 3: The evolution of the daily EUA closing prices.
Source: Point Carbon, own depiction

Why the German Manufacturing Sector?

Germany → the largest economy and the largest emitter of greenhouse gases in the EU

- **Manufacturing Sector** → The backbone of the German economy
- 20 percent in employment (2016)
- 25 percent in GDP (2016)
- 20 percent of Germany's carbon dioxide emissions (2016)

Allocative, Technical and Cost efficiency

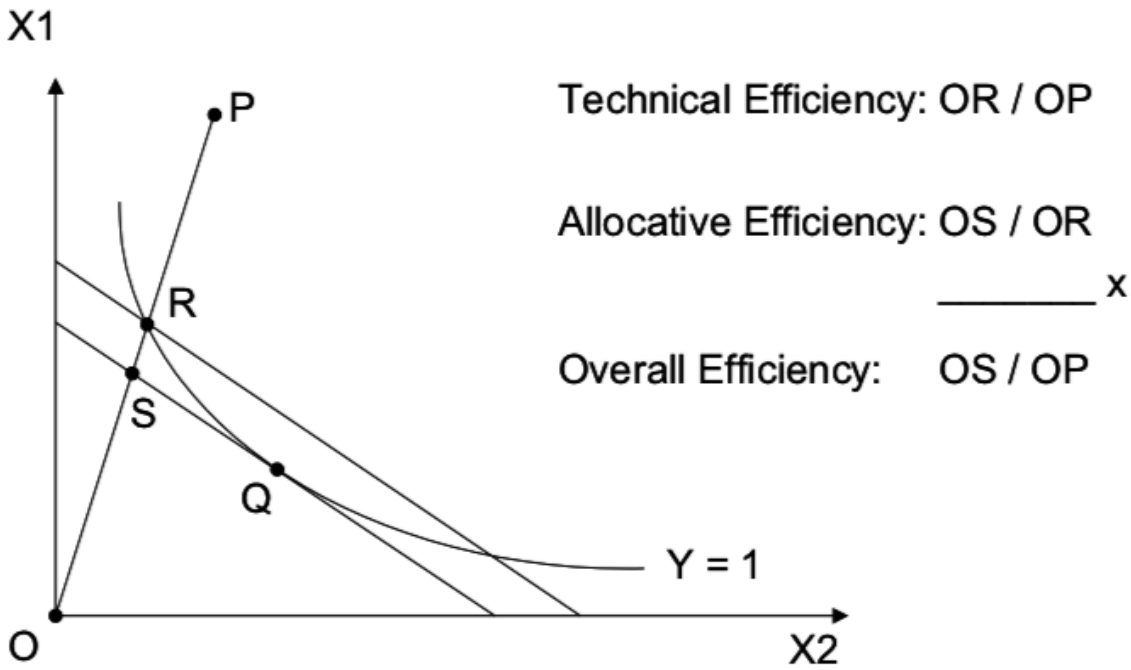


Figure 4: Source: McGlynn et al. (2008)

Battese, G. E. and T. J. Coelli (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics 20*(2), 325–332.

Huang, C. J., T.-H. Huang, and N.-H. Liu (2014). A new approach to estimating the metafrontier production function based on a stochastic frontier framework. *Journal of productivity Analysis 42*(3), 241–254.